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Anomalous magnetoresistance in multy-level 2D systems

N. S. Averkiev, L. E. Golub and G. E. Pikus
Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia

A weak localization is a quantum interference of waves propagating through the closed trajectory in the opposite directions. This interference may be destroyed by different wave phase breaking processes: magnetic field, inelastic processes, spin relaxation etc. These mechanisms give additive contributions in the total interference breaking rate.

An additional channel of interference breaking appears in quantum wells (QWs) with a few subbands of size quantization: intersubband transitions. The peculiarity of this mechanism is that its role is not restricted to the formal change of the total interference breaking time. This relates with the fact that only the states with both the same energy and momentum give the contribution to the weak localization. Since the states at the Fermi level in different subbands have different momenta there are no interference between them.

One can show that the role of the intersubband transitions leads to the averaging of the parameters which defines the weak localization. The way of the averaging depends on the relation between the interlevel transition time and the times of phase breaking due to other processes. In intensively investigated QWs with a few filled subbands of size quantization this relation can change in wide range. In this report the weak localization theory for n- and p-type QWs in which carriers occupy a few size-quantized levels is proposed.

We have shown that the anomalous contribution to the magnetoconductivity in classically weak magnetic fields H in 2D multy-level systems is described by the following expression:

$$\sigma(H)-\sigma(0)=\frac{e^2}{4\pi^2\hbar}\sum_{n=1}^{N}\left[2f_2\left(\frac{H}{H_1^{(n)}}\right)+f_2\left(\frac{H}{H_2^{(n)}}\right)-f_2\left(\frac{H}{H_3^{(n)}}\right)\right], \qquad (1)$$

where N coincides with the number of filled size-quantized subbands in QW and f_2 is the standard function:

$$f_2(x)=\ln x+\psi(1/2+1/x),$$

where $\psi(y)$ is the digamma function. The first and second terms in (1) are the contributions of the states with unit total momentum and projections ± 1 and 0 respectively and the third term is the contribution of the states with zero total momentum. $H_{1,2,3}^{(n)}$ are characteristic magnetic fields which defined by times of inelastic scattering, spin relaxation and interlevel transitions.

The analysis shows that if the intersubband transition time is more than the times of phase breaking due to elastic and inelastic processes then each level of size quantization gives independent contribution to the anomalous magnetoresistance and n in the expression (1) coincides with the numbers of size-quantized levels. In the case of intensive intersubband transitions the conributions from the different subbands average and the characteristic magnetic fields are defined by effective times of spin and phase

relaxation. For instnance, we have calculated the values of the characteristic magnetic fields in the most actual case of two size-quantized subbands filling.

The other peculiarity of the intersubband elastic transitions is that they accompanied by a large (the same order as the inverse QW' size) change of the quasimomentum. Therefore their intensity depends on the sort of the scattered potential: if it is short-range then the intersubband transition time may be comparable with the momentum relaxation time. In p-type QWs, where the spin relaxation time in the subband decreases with its filling, the intensive intersubband transitions lead to the destroying of the interference of the states with unit total momentum even in the subbands with small number of carriers. Experimentally it must manifest in that, according to (1), the magnetoconductivity is negative. In n-type QWs the intensive intersubband transitions effect only on the value of the diffusion coefficient and the magnetoconductivity may be positive.

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